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## A PRODUCT AND METHOD OF BRAZING USING KINETIC SPRAYED COATINGS

### TECHNICAL FIELD

The present invention is directed to a process for preparing aluminum and aluminum alloy and other metal tubes, plates and other components used in heat exchangers such as condensers, radiators and evaporators for brazing by depositing thereon a kinetic sprayed brazing composition. The single-step process deposits monolith or composite coatings that may comprise one or more brazing materials such as a corrosion protector, a brazing filler and a brazing flux.

### INCORPORATION BY REFERENCE

U.S. Patent No. 6,139,913, entitled "Kinetic Spray Coating Method and Apparatus" is incorporated by reference herein.

### BACKGROUND OF THE INVENTION

Heat exchangers such as condensers, radiators, evaporators, heater cores and coolers made of aluminum or aluminum alloy (generally referred to hereinafter as "aluminum") or other metals are widely used today. These heat exchangers generally include perforated fins brazed to the external surfaces of tubes and plates that form the structure of the heat exchanger. The tubes are usually extruded and the fins are usually made from sheets.

Prior to assembly into heat exchangers the tubes and plates are typically coated (or plated) with a corrosion protector using known techniques such as twin-wire arc thermal spraying. Zinc or zinc-aluminum alloys are generally used as the corrosion protector, but any known corrosion inhibitor may be used. The fins are prepared prior to assembly to carry the brazing filler that fills the joints between the tube and fins during brazing. The brazing filler is applied to fin sheet stock as a cladding layer in the form of an overlaid sheet that is rolled and bonded onto the aluminum fin sheet. The



cladding consists of a material or materials known in the art to be capable of melting at a temperature lower than the heat exchanger aluminum such as an aluminum-silicon alloy so that, during brazing, the cladding will form brazed joints. The use of such clad brazing sheets is well known and commonly used, even though it is well known that the use of clad brazing sheets adds to production costs and accelerates tool wear.

Prior to brazing of aluminum heat exchangers, tube cladding and plate surfaces must be cleaned and de-oxidized. Removal of the oxidation layer is necessary in order to form strong joints. This is generally accomplished using a material commonly known as flux that chemically cleans and de-oxidizes the surface and protects the aluminum from further oxidation. The flux is applied to the aluminum surfaces of plates and tubes prior to brazing using techniques such as flux showering or electrostatic spraying. During brazing, the flux material further serves to reduce the filler metal's surface tension and promote wetting of the materials to assist in joint formation. While many flux materials are known and used, Nocolok® Flux (a mixture of potassium fluoroaluminate salts manufactured by Solvay Fluor), and similarly formulated fluxes, are preferred due to their non-corrosive effect on aluminum after brazing. The components of the heat exchanger are finally joined together by bringing the assembly to brazing temperature in a controlled atmosphere brazing furnace, a vacuum furnace, or the like.

To summarize, aluminum heat exchangers for automotive vehicles and other applications, today, are manufactured by flux brazing of filler-clad fin sheets to zinc-coated plates and tubes. The fin sheets are clad with brazing filler in one process, the plates and tubes are coated with zinc in a second process and the brazing flux is applied in a third process.

An alternative method of preparing heat exchanger components for aluminum brazing is disclosed in U.S. Patent No. 5,907,761. In the '761 patent, a solvent-based brazing composition is coated onto components using known techniques such as dip coating or liquid spray coating. The disclosed brazing composition includes, (1) a powdered alloy of aluminum, silicon, zinc, and indium (or beryllium), (2) a polymeric resin binder, (3) an aliphatic alcohol solvent, and (4) a brazing flux. In the

patent, an alloy is first formed from powders of aluminum, silicon, zinc and indium. The alloy is then made into a powder and mixed with the polymer binder, solvent and flux. The resulting liquid brazing composition is then applied to the substrate using known techniques and becomes bound to the substrate by action of the polymer resin.

5 Brazing follows.

#### SUMMARY OF THE INVENTION

By the process of the present invention, aluminum and other metal heat exchanger components are prepared for brazing using a new technique that replaces the multi-step operations of the prior art. The present invention provides a means to simultaneously clean and deoxidize heat exchanger components and bond all braze materials onto the components in a single operation. Individual zinc plating, filler cladding and separate flux application (for pre-cleaning, deoxidizing and braze flux deposition) can thereby be replaced. In addition, no solvent base or other liquid system is necessary.

The present invention generally applies a new technique for producing coatings known as kinetic spray or cold gas dynamic spray to brazing. This new technology has been reported in an article by T.H. Van Steenkiste et al., entitled "Kinetic Spray Coatings," published in Surface and Coatings Technology, vol. 111, pages 62-71, Jan. 10, 1999. The article discusses producing continuous layer coatings having low porosity, high adhesion, low oxide content and low thermal stress. The article describes coatings being produced by entraining metal powders in an accelerated air stream and projecting them against a target substrate. It was found that the particles that formed the coating did not melt or thermally soften prior to impingement onto the substrate.

The Van Steenkiste et al. work improved upon earlier work by Alkimov et al. as disclosed in U.S. Patent No. 5,302,414, issued April 12, 1994. Alkimov et al. disclosed an apparatus and process for producing dense layer coatings with powder particles having a particle size of from 1 to 50 microns using a supersonic spray operating at low temperatures and pressures.

The Van Steenkiste et al. article reported on work conducted by the National Center for Manufacturing Sciences (NCMS) to improve on the earlier Alkimov process and apparatus. Van Steenkiste et al. demonstrated that Alkimov's apparatus and process could be modified to produce kinetic sprayed continuous layer coatings using particle sizes of greater than 50 microns and up to about 106 microns. This modified process and apparatus for producing such larger particle size kinetic spray continuous layer coatings is disclosed in U.S. Patent No. 6,139,913, Van Steenkiste et al., that issued on October 31, 2000. The process and apparatus provide for heating a high pressure air flow up to about 650°C and accelerating it with entrained particles through a de Laval-type nozzle to an exit velocity of between about 300 m/s (meters per second) to about 1000 m/s. The thus accelerated particles are directed toward and impact upon a target substrate with sufficient kinetic energy to impinge the particles to the surface of the substrate. The temperatures and pressures used are sufficiently lower than that necessary to cause particle melting or thermal softening of the selected particle so that no phase transformation occurs in the particles prior to impingement.

The present invention provides a method for replacing, with a single process, the several processes currently used in brazing heat exchangers such as condensers, radiators, evaporators, and the like. The single spraying operation can generate a single layer or multiple layers of a monolith or composite coating.

The process of the invention involves kinetic spraying onto metal substrates a brazing composition that comprises corrosion protector, brazing filler and/or flux. In a preferred embodiment, the brazing composition comprises zinc or zinc-aluminum alloy as a corrosion protector, silicon or aluminum-silicon alloy as a brazing filler, and Nocolok® Flux or similar fluxing material as the flux. In another preferred embodiment, the brazing composition comprises a ternary alloy of aluminum-zinc-silicon powder and flux. In yet another preferred embodiment, the brazing composition comprises a pre-homogenized mechanical mixture of separate powders of aluminum, zinc, silicon and flux.



The process of the present invention may be used for brazing any metal surface and is not limited to use in heat exchangers. The advantage of the present invention is that it offers a simple yet versatile process for brazing metal surfaces.

The process provides an effective means for coating a brazing composition onto aluminum substrates that obviates the need for pre-fluxing, filler cladding and separate corrosion protector application. The process of the present invention may be used advantageously during any stage of processing including, for example, from immediately following tube extrusion to immediately prior to brazing.

Kinetic spray deposition is a relatively new technique where powders, especially of metal (or ceramic) particles, are accelerated in a pre-heated gas stream toward a substrate at high velocities between about 300 m/s (meters per second) to about 1000 m/s. Upon impact, the metal particles initially grit blast the surface and then plastically deform and impinge bond onto the surface. Subsequent particles bond with the deposited particles upon impact to form a surface layer coating.

Prior to the present invention, it was unexpected that kinetic spray could be suitably used to deposit braze compositions onto aluminum surfaces in a manner that would produce satisfactory braze joints. The process as used in the present invention applies the kinetic spray technology disclosed in U.S. Patent No. 6,139,913, incorporated herein by reference, to the preparation of aluminum surfaces for brazing.

The process of the present invention is superior over known techniques. The kinetic sprayed powders in the braze composition never reach their melting temperature and always remain in their original solid phase during the spray process. Since the powders do not reach the molten state, little oxidation of the powders occur and a relatively oxide free coating can be formed. In addition, kinetic sprayed braze compositions offer the added advantage in that the aluminum components being coated need not be pre-fluxed (i.e., pre-cleaned and deoxidized) since the initial grit blasting action inherently cleans and de-oxidizes the surface as the brazing composition surface layer is being applied. Furthermore, while inert atmosphere processing is generally required for thermal spraying, as used in prior art processes to lessen the formation of

oxidation during coating deposition, an inert atmosphere is not necessary in kinetic spray deposition, and the associated costs are thereby avoided.

A primary benefit of the present invention is the ability to mix different materials having different properties together and apply them as a composite coating.

- 5 Because the powders are not melted in the kinetic spray process, the materials do not chemically combine or alloy in the kinetic spray process. The synergistic benefits of the various materials may, thereby, be taken advantage of in the most effective and efficient manner.

- 10 In development of the present invention, it was further discovered that kinetic spray is useful in coating alloys onto aluminum surfaces that have a substantially greater hardness than aluminum. It has now been found that ternary alloys such as zinc-aluminum-silicon alloys may be kinetic spray-coated onto aluminum substrates such as plate and tube surfaces. While specific materials are disclosed herein, it is clear from the versatility of the present invention that alloys of other braze materials may be  
15 similarly used.

- Using the process of the present invention in aluminum brazing, any conceivable brazing composition may now be used as a single stage coating. Pre-fluxing and the use of a separate flux coating are no longer required. Instead, cleaning and deoxidizing are accomplished simultaneous to coating, and brazing flux may be  
20 incorporated into the coating itself. Accordingly, fluxless brazing is now possible. The present process also allows the incorporation of brazing filler into the coating so that cladding is no longer required. Accordingly, cladless brazing is now also possible. The brazing composition can comprise monoliths or composites of individual powders, alloy powders or their combinations to provide maximum versatility.

- 25 Cladless and fluxless brazing are now possible and a pre-coating of a corrosion protector is no longer necessary. The present invention provides the ability to incorporate corrosion protector, brazing filler and flux into a single coating composition and the means for coating that composition onto aluminum surfaces while simultaneously cleaning and deoxidizing the surface.

## BRIEF DESCRIPTION OF THE DRAWINGS

Figs. 1A and 1B are SEM micrographs showing microstructures of two composite coatings of aluminum-silicon alloy and zinc of the present invention.

5 Figs. 2A, 2B, 2C, and 2D are SEM images of composite coatings of aluminum and zinc of the present invention.

Figs. 3A, 3B, 3C, and 3D are cross-sectional SEM images of the same coatings, respectively, as shown in Fig. 2.

10 Figs. 4A, 4B, 4C, and 4D are mappings of the elements of a composite coating of aluminum, zinc and silicon of the present invention. Fig. 4E is an energy dispersive spectrum of the composite coating.

Figs. 5A, 5B, 5C, 5D and 5E are mappings of various elements of zinc and aluminum-silicon alloy coating with directly incorporated Nocolok® flux as in the present invention. Fig. 5F is the energy dispersive spectrum of the alloy coating.

15 Figs. 6A and 6B are elemental mappings of a fin-tube assembly brazed with aluminum-zinc-silicon alloys according to the present invention, and Fig. 6C depicts a mapping of an assembly brazed with an alloy according to the prior art.

Figs. 7A and 7B are SEM micrographs of the brazing results for zinc and aluminum-silicon alloy coatings of the present invention.

20 Fig. 8 depicts a small assembly of tubes brazed to aluminum fin material using a composite coating of aluminum and zinc of the present invention.

Figs. 9A and 9B are SEM micrographs showing the surface morphology of a tube as in Fig. 8 before and after brazing, respectively.

25 Figs. 10A and 10B are examples of the joints brazed according to the present invention using an aluminum-rich coating and a zinc-rich coating, respectively (both are composite coatings of aluminum and zinc).

Figs. 11A and 11B are elemental mapping results showing that zinc deposited on aluminum tubes according to the present invention is uniformly distributed on the surface after brazing.

30 Figs. 12A and 12B are elemental mappings of aluminum-zinc-silicon alloy coatings showing brazed fin and tube assemblies of the present invention.

## DESCRIPTION OF THE PREFERRED EMBODIMENT

In the construction of a heat exchanger comprising fins and tubes, an extruded aluminum condenser tube is prepared for brazing aluminum fins thereon by kinetic spraying a brazing composition on the tube or other surface. The brazing composition is a solid phase monolith or composite that generally comprises particles of corrosion protector, filler material, and/or flux.

The brazing composition is selected from solid phase particles having a particle size (diameter or equivalent) distribution in the range of about 10 microns to about 150 microns, with a particle size distribution of greater than about 45 microns being preferred. The particles may further be either spherical or irregular shaped (such as granular). When the solid phase material is a monolith, it is preferred that the composition be selected from zinc, zinc-aluminum alloy, aluminum-silicon alloy, aluminum-zinc-silicon alloy and aluminum-zinc-silicon-copper alloy. When the solid phase material is a composite, it is preferred that the composition be selected from a combination of two or more of the following: zinc, zinc-aluminum alloy, aluminum, silicon, aluminum-silicon alloy, aluminum-zinc-silicon alloy and aluminum-zinc-silicon-copper alloy. It is preferred that a non-corrosive flux, such as Nocolok® flux or the like, be added to monolith or composite particles in preparing the brazing composition to be used.

The kinetic spray technique used in the present invention is primarily as disclosed in U.S. Patent No. 6,139,913, the teachings of which are incorporated herein by reference.

In the present invention, the brazing composition is introduced into a focused gas stream traveling at a velocity of about 300 m/s (meters per second) to about 1000 m/s. The gas stream is preferably preheated to a temperature of from about 100°C to about 300°C, and more preferably to about 200°C. As the particles of the brazing composition are entrained into the gas stream, they begin to gain kinetic and thermal energy. The brazing composition is then accelerated through a de Laval-type nozzle to achieve an exit velocity of up to about 1000 m/s directed toward the tube surface (i.e.,

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the substrate being sprayed). The tube is moved across the path of the exit stream (or vice versa) to lay a coating on the surface of the tube. The tube is passed across the exit stream as necessary to create one or more layers.

As particles of the brazing composition impact the surface, kinetic energy is transferred to the aluminum surface. The impact of the particles initially grit blast the surface thereby fracturing any surface oxide layer, and simultaneously begin mechanically deforming and impingement bonding the particles to the surface. Successive layers are formed by the entrained particles impacting and bonding to other particles deposited on the surface. The particles deposited on the surface while undergoing plastic deformation remain in their original solid phase (i.e., they do not melt).

An aluminum substrate made according to the invention comprises an aluminum surface and a kinetically impinged coating bonded to its surface. The coating is a solid phase monolith or composite comprising one or more of corrosion protector for aluminum, filler material for brazing, and/or brazing flux. The coating may have multiple layers kinetically bonded directly to the aluminum surface. Each layer is substantially free of oxides and retains the physical properties and solid phase of the original pre-coating composition.

According to the present invention, the following coatings were prepared, kinetically sprayed onto aluminum brazing substrates and brazed. All showed good brazing results. While representative of the present invention, the following examples are not intended to limit the scope of the invention in any way.

### EXAMPLES

Both monolith and composite coatings of various compositions were prepared including:

- (a) zinc coatings with an average loading of about 50 g/sq.m. (grams per square meter) to about 400 g/sq.m.;

(b) zinc-aluminum alloy coatings with an average loading of about 100 g/sq.m. to about 600 g/sq.m. (having melting points of alloys lower than 600°C);

(c) aluminum-silicon alloy coatings with an average loading of about 10 g/sq.m. to about 200 g/sq.m. with aluminum-silicon alloy starting powders having a composition of about 12% silicon by weight (i.e. the eutectic composition);

(d) aluminum-zinc-silicon ternary alloy coatings with starting powders having about 50% to about 78% aluminum, about 12% to about 45% zinc, and about 5% to about 10% silicon (all %'s by weight);

(e) aluminum-zinc-silicon-copper quaternary alloy coatings with average loading of about 20 g/sq.m. to about 150 g/sq.m. and with starting powders having about 50% to about 78% aluminum, about 10% to about 45% zinc, about 4% to about 10% silicon, about 0.1% to about 5% copper and trace amounts of other alloying elements such as iron, nickel, titanium and bismuth (all %'s by weight);

(f) composite coatings of aluminum and zinc, preferably with greater than about 40% by weight of zinc in the starting mixture;

(g) composite coatings of zinc and aluminum-silicon, preferably with about 6% to about 70% by weight of zinc in the starting mixture;

(h) composite coatings of aluminum, zinc and silicon with about 10% to about 20% silicon by weight in the starting powder, and preferably with about 15% silicon by weight; with the ratio of aluminum to zinc in the range of about 4 to about 0.6;

(i) coatings with starting powders as provided in (a), (b), (d), (e), (f), (g) and (h) with directly incorporated Nocolok® flux;

(j) coatings of (i) with a larger amount of Nocolok® flux incorporated as a metallized flux (in which the mixed powders of metals and flux were melted or sintered into ingots and then powdered and used as the kinetic sprayed composition).

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Microstructural and chemical analyses of the above coatings were performed. Selected results are shown in Figs. 1 through 5 that illustrate the general characteristics of these kinetic spray-deposited coatings.

Figs. 1A and 1B are plane-view SEM micrographs showing the microstructures of the aluminum-silicon alloy and zinc coatings as in (g), above, deposited from starting powders with 6% and 10% zinc, respectively. The spherical-shaped particles with darker contrast are the aluminum-silicon alloy and the remainder is zinc.

Figs. 2A, 2B, 2C, and 2D show the plane view SEM images of the composite coatings of aluminum and zinc as in (c), above, which were deposited from two types of starting powders using two traverse speeds. Similar to Fig. 1, the spherical-shaped particles with darker contrast are the aluminum and the remainder is zinc.

Figs. 3A, 3B, 3C, and 3D are the cross-sectional SEM images of the same coatings shown in Fig. 2. In these cross-sectional images, aluminum and zinc particles can be readily distinguished by their respective contrasts, with aluminum shown with the dark contrast and zinc shown with the bright contrast.

Figures 4 A-D present the cross-sectional elemental mappings of a composite coating of aluminum, zinc and silicon as in (h), above, showing mappings of aluminum (Fig. 4A), zinc (Fig. 4B), silicon (Fig. 4C); and Fig. 4D shows an overlay of Figs. A-C. These mappings and the energy dispersive spectrum in Fig. 4E indicate the incorporation of silicon in the coating. Silicon is a rapid diffuser in aluminum and can effectively promote the melting of aluminum at the brazing temperature.

Fig. 5A is a SEM image of a zinc and aluminum-silicon alloy coating with directly incorporated Nocolok® flux as in (i) combined with (g), above; and Figs. 5 B-E are elemental mappings of zinc (Fig. 5B), silicon (Fig. 5C), fluorine (Fig. 5D) and potassium (Fig. 5E). The starting powder used for this coating contains about 6% by weight flux and about 94% of a mixture of zinc and aluminum-silicon alloy. Both elements F (fluorine) and K (potassium), which are chemical constituents of Nocolok® Flux (that has a general chemical formula of  $\text{KAIF}$ ), displayed strong peaks in the

energy dispersive spectrum of Fig. 5F. This shows that a significant amount of flux was incorporated into the coating via the kinetic spray process. Moreover, the relatively uniform distribution of K and F presented by the elemental mappings of Figs. 5 A-E indicates that the flux was uniformly distributed.

5 Figs. 6A, 6B and 6C are zinc elemental mappings of brazed fin-tube assemblies: Figs. 6A and 6B show alloy assemblies prepared according to the present invention, while Fig. 6C shows an alloy prepared according to the prior art. As shown, the mappings of Figs. 6A and 6B compare well with Fig. 6C demonstrating uniform zinc distribution in the surface layer (as a corrosion protector) for the assemblies in Figs. 6A and 6B.

10 The brazability of the coatings, using known processes, was examined using small assemblies of cladless fin stock and extruded aluminum tubes with the kinetic sprayed coatings. Brazing was conducted at a brazing temperature of about 600°C for about 5 to about 15 minutes under about 1 atmosphere of nitrogen. The brazing properties of the coatings were evaluated by cross-sectional SEM examination of the brazed joints. Pull tests were also performed to demonstrate the critical load needed to pull off a fin from the aluminum tube. The results are summarized as follows.

15 Composite coatings of zinc and aluminum-silicon alloy: These coatings generally exhibited good brazability under pre-fluxing conditions. The flux was applied prior to brazing experiments by either dipping or spraying the small assemblies with an alcohol or a water solution having a flux concentration of from about 5% to about 20%. Figs. 7A and 7B provide SEM micrographs of the brazing results for 15% and 20% by weight zinc, respectively. As shown, very homogeneous and well-shaped brazing joints were formed. Pull tests were also conducted on the brazed joints as shown in table 1 below. Brazed components of the present invention compared well with commercially available products known in the art (having a threshold of about  $10.2 \pm 1.2$  kg). The results further showed that there was no significant dependence of brazing results based upon variations in the tested compositions or the average coating thickness (i.e. the loading of a coating).

**Table 1: Brazing properties of small fin and tube assemblies using kinetic spray deposited composite coatings of zinc and aluminum-silicon alloy**

Starting Powders	Brazing Conditions			Results of Brazing		
	Temp (°C)	Time (Min)	N <sub>2</sub> (atm)	Pre-fluxed		Not-fluxed
				Brazing Result	Pull Tests	Brazing Result
6%Zn+ 94% Al-Si	600°C	10	1	Good	12.8±0.9 kg Failed at Fin/Joint	BWH
10%Zn+ 90% Al-Si	600°C	10	1	Good	13.8±1.0 kg Failed at Fin/Joint	BWH
15%Zn+ 85% Al-Si	600°C	10	1	Good	10.9±0.8 kg Failed at Fin/Joint	BWH
20%Zn+ 80% Al-Si	600°C	10	1	Good	11.4±1.1 kg Failed at Fin	BWH

BWH: breakable with hands

For the standard product, failures under the pull test occur at 10.2±1.2 kg. and breakage predominantly takes place at braze joint.

Composite coatings of aluminum and zinc: Without using flux, good brazing results were achieved for high zinc-content coatings. Fig. 8 depicts a small assembly of tubes brazed to aluminum fin material using a high zinc-content aluminum/zinc coating according to the process of the present invention. The assembly was brazed at 600°C for 8 minutes in a nitrogen atmosphere without flux. Scanning electron micrographs show the difference in the surface morphology of the tube before brazing (Fig. 9A) and after brazing (Fig. 9B), showing that the braze composition coating on the tube surface melted as necessary to form a joint. The brazing results for selected aluminum and zinc coatings are summarized in Table 2. While brazability was better for pre-fluxed substrates, brazing without pre-fluxing was demonstrated.

**Table 2: Brazing conditions and results using the composite aluminum and zinc coatings**

Brazing Conditions				Brazing Results			
Flux	N <sub>2</sub> (atm)	Temp (°C)	Time (min)	Starting Powder A Al (40%)+Zn (60%)		Starting Powder B Al (60%)+Zn (40%)	
				Brazability	Pull Test Load/Failure	Brazability	Pull Test
No	1	600	5	Not Brazed		Not Brazed	
	1	600	10	Brazed (UBWH)	2.7 kg	Not Brazed	
					Joint only		
Yes	1	600	15	Brazed (UBWH)		Brazed (BWH)	
	1	600	5	Brazed (UBWH)	8.2±3.8kg	Brazed (UBWH)	9.4±4.1kg
					Joint only		Joint only
	1	600	10	Brazed (UBWH)	10.7±1.0kg	Brazed (UBWH)	10.7±1.8kg
					Joint only		Joint only
	1	600	15	Brazed (UBWH)	8.1±2.2kg	Brazed (UBWH)	10.1±2.1kg
					Joint only		Joint only

UBWH: unbreakable with hands; BWH: Breakable with hands

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Composite coatings of aluminum, zinc and silicon (i.e., the tri-powder coating): Coatings were tested with compositions having about 34% to about 68% aluminum, about 17% to about 51% zinc, and about 15% silicon (all by weight) with loadings of about 75 g/sq.m. (grams per square meter) to about 375 g/sq.m. All of the coatings generally showed very good brazing properties. Figs. 10A and 10B show examples of the brazing joints produced using an aluminum-rich coating and a zinc-rich coating, respectively. Since silicon is a rapid diffuser in aluminum, the incorporation of silicon helps the melting of aluminum during the brazing process. As a result, good brazability was achieved for the tri-powder coatings with a large variation in the aluminum to zinc ratios.

Composite coatings of zinc and aluminum-silicon alloy with directly incorporated flux: Good brazability was found using flux-incorporated coatings without pre-fluxing the test assembly.

For both composite coatings of aluminum and zinc, and composite coatings of aluminum alloy and zinc, zinc was incorporated into the coatings primarily to promote coating formation as a binder and to enhance corrosion resistance. Because of the volatile nature of zinc, some loss of zinc during the brazing process is expected, while a major loss of zinc would be of concern. Elemental mapping was performed on selected specimens. The results indicate that substantially larger amounts of zinc remained on the surface of tubes than expected. Figs. 11A and 11B show an example of elemental mapping results, indicating that zinc uniformly distributed on the surface of aluminum tubes.

Coatings of aluminum-zinc-silicon alloy: The coatings exhibited superior brazing properties. With alloy coatings, it was found that a continuous layer coating was not required to achieve satisfactory brazing results. It was also found, as shown in Figs. 12A and 12B that the zinc was uniformly distributed in the coating, which is more desirable for corrosion protection. The results of a SWAAT test (a standard corrosion test for condensers) indicates that the assemblies brazed with aluminum-zinc-silicon

While the preferred embodiment of the present invention has been described so as to enable one skilled in the art to practice the process of preparing aluminum surfaces for brazing, it is to be understood that variations and modifications may be employed without departing from the concept and intent of the present invention as defined by the following claims. The preceding description is intended to be exemplary and should not be used to limit the scope of the invention. The scope of the invention should be determined only by reference to the following claims.